CONCEPTS FOR ELIC - A HIGH LUMINOSITY CEBAF BASED ELECTRON-LIGHT ION COLLIDER

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Abstract A CEBAF accelerator based electron-light ion collider (ELIC) of rest mass energy from 20 to 65 GeV and luminosity from 10^{33} to 10^{35} $cm^{-2}s^{-1}$ with both beams polarized is envisioned as a future upgrade to CEBAF. A two step upgrade scenario is under study: CEBAF accelerator-ring-ring scheme (CRR) as the first step, and a multi-turn ERL-ring as the second step, to attain a better electron emittance and maximum luminosity. In this paper we report results of our studies of the CRR version of ELIC.

1. INTRODUCTION

Thirty years after the establishment of QCD as the theory of the strong nuclear interaction, and despite significant progress towards understanding of the structure of hadronic matter, some crucial questions involving the role and behavior of quarks and gluons in atomic nuclei remain open. In particular, one would like to: 1) develop a quantitative understanding of the contribution of gluons to the binding and the spin of the nucleon; 2) learn how the dynamics of confinement leads to the formation of hadrons – a key aspect of the transition from the deconfined state of free quarks and gluons in the Big Bang to stable hadron matter; and 3) determine how the nuclear medium affects quarks and gluons [1].

An electron-light ion collider of rest mass energy up to 60 to 65 GeV and luminosity from 10^{33} to 10^{35} $cm^{-2}s^{-1}$ would be a powerful tool to answer these questions.

2 THE ELIC COMPLEX

Such high luminosity collider is envisioned as a future upgrade to CEBAF, following the re-circulating superconducting RF linac upgrade to 12 GeV fixed target program [2]. The CEBAF with polarized injector can be used as full energy injector for 3-7 GeV, 1-3 A electron ring. By adding a positron source to CEBAF injector, positron beam also can be accelerated in CEBAF and accumulated and polarized in same storage ring. To attain the required *ion beams*, we propose to build an ion facility, a major component of which is a 150 GeV, 1 A collider ring with 4 interaction regions. The booster rings, electron collider ring, and the ion collider ring are designed as a figure 8. Such configuration eliminates the issue of spin maintenance at acceleration and allows one to easily arrange desired spin orientation and flipping for all ion species at all energies. Other critical component of the ion complex is a 75 MeV ERL-based *continuous electron cooling* (EC), which is anticipated to provide low emittance and simultaneously very short ion bunches. The short bunches have two critical advantages: 1) a *super-strong beam focusing* at the collision points and 2) *crab-crossing colliding beams*. The highest bunch repetition rate (up to CEBAF's RF frequency of 1.5 GHz) is envisioned for maximum attainable luminosity.

The ELIC facility is designed to produce a variety of polarized light ion species: p, d, ^{3}He and Li, and unpolarized light to medium ion species. Longitudinally and transversally spin-polarized light ion beams in the ring at all energies, with the flexibility of switching from longitudinal to transverse spin in the detectors, as well as fast flipping of the spin are of critical importance to the science.

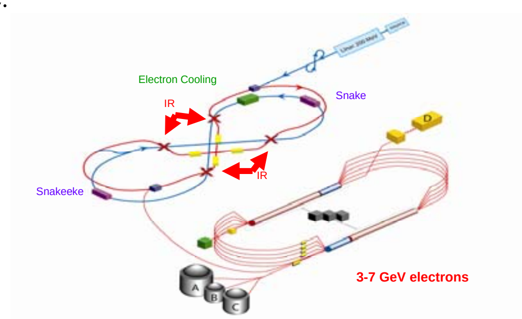

Fig.1: ELIC general layout. The e-collider ring (arcs) also is used as a large booster for the ion beam (before accumulating the e-beam).

3 THE ELIC LUMINOSITY CONCEPT

The concept of ELIC luminosity has been established based on considerations of the beam-beam, space charge, intrabeam scattering and electron cooling effects [3,4].

1. Electron cooling in cooperation with bunching SRF resonators provides very short ion bunches (5 mm or less), thus making sense to design a short beta-star.
2. Reduction of transverse emittance by EC allows one to increase beam extension in the final focusing magnet, hence, reach a lower beta-star.
3. Short bunches make possible implementing the crab-crossing colliding beams that allows one to eliminate parasitic beam-beam interactions [3,10] and avoid beam bend at detector area while approaching a highest collision rate (Fig 2).
4. Reduction of charge/bunch increases beam stability against microwave interaction (electron cloud, in particular).
5. Large synchrotron tune (exceeding the beam-beam tune shift in ELIC case) eliminates the synchro-betatron non-

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linear resonances in beam-beam interaction, thus allowing one to reach a large beam-beam tune shift.

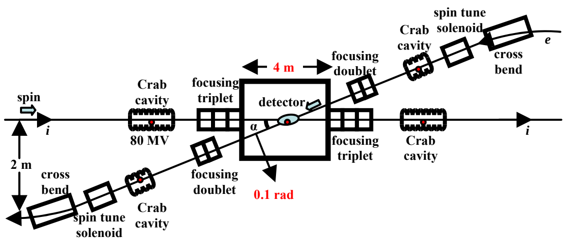

Fig.2: Crab crossing interaction region of ELIC

6. Flat beams (by lowering the x-y coupling at fixed beam area) lead to reduction of IBS rate against EC
7. Equidistant fraction phase advance between four IPs of ELIC effectively reduces the critical beam-beam tune shift to a value normalized to one IP.

Table 1: Basic parameters for ELIC

Parameter	Unit	Value	Value	Value
Beam Energy	GeV	150/7	100/5	30/3
Circumference	KM	1.5		
Crossing straights	M	346 x 2		
Bunch collision rate	GHz	1.5		
# of particles/bunch	10^{10}	.4/1.0	.4/1.1	.12/1.7
Beam current	A	½.4	1/2.7	.3/4.1
Energy spread, rms	10^{-4}	3		
Bunch length, rms	mm	5		
Beta-star	mm	5		
IP focal parameter	M	6		
Space for detector	M	5		
Extended beam size*	mm	6		
Crab crossing angle	rad	.1	.1	.1
Crab field integral	TM	.24	.16	.048
Horizontal emit. norm.	μm	1/100	.7/70	.2/43
Vertical emit., norm.	μm	.04/4	.06/6	.2/43
Beam-beam tune shift (vertical) per IP		.01/.086	.01/.073	.01/.007
Space charge tune shift in p-beam		.015	.03	.06
Lumi. per. IP*, 10^{34}	$cm^{-2}s^{-1}$	7.7	5.6	.8
Luminosity lifetime	h	24	24	>24

*) Beam horizontal size in IP focusing triplet

2 e-BEAMS OF ELIC

Our earlier studies of EIC concepts concentrated on schemes based on use of energy recovering superconducting linac (ERL) [3-5]. The ERL version with or without *circulator* promises a higher luminosity. However, it challenges one with developments of high current polarized source (one loop ERL) and fast beam kickers (ERL with circulator-collider ring). Therefore, we also develop a CEBAF based ring-ring version of ELIC.

ACCUMULATING ELECTRON BEAM

CEBAF accelerator 3 to 10 GeV with 1 mAmp 1.5 GHz CW polarized beam can be used for injecting and stacking full energy polarized e-beam in electron storage ring by use of synchrotron radiation (damping time 50ms at 3 GeV to 1.5 ms at 10 GeV). At stacking, a single pulse current of a duration about 50 μs might add up to about 10 mA in storage ring (10 times circumference multi-turn injection). Accumulation time for 3A circulating current (300 injections) at 10 GeV is then about 0.5 s. An alternative regime might be a continuous low current injection to compensate for beam loss in the ring .

PRODUCING AND POLARIZING POSITRON BEAM

We also propose to generate and accumulate positron beam by use CEBAF 130 MeV injector as shown in Fig.3. After stacking in storage ring, the beam can be polarized by Sokolov-Ternov mechanism.

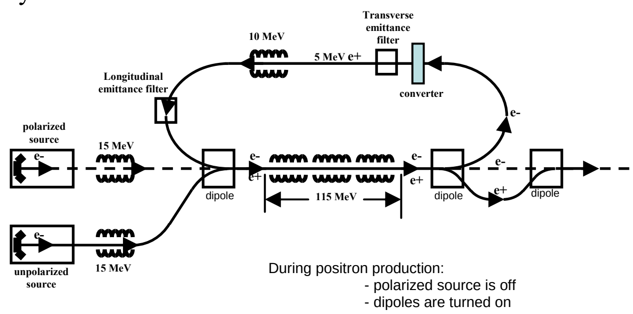

Fig.3: Schematics of CEBAF injector based positron generator/injector

In energy range of electron beam 100-200 MeV, modern design convertors can be accounted for stacking positron beam with rate about 0.1 A/min [11].

SPIN IN e-RING

A special spin rotation scheme has been developed to transform e-spin from vertical in arcs to longitudinal in IPs in a wide energy range (5 to 10 GeV or wider) at unchanged orbit. It is based on use of SC solenoids and involves energy dependent spin rotation by vertical cross bends of IPs associated with crab crossing (Fig. 4). Spin-stabilizing solenoids are introduced around each IP in order to provide (ultimate) the ½ value of the global spin tune in the ring. This removes spin resonances and makes polarization insensitive to energy. Self-polarization in arcs supports the injected polarization of electron beam and provides polarization of positron beam.

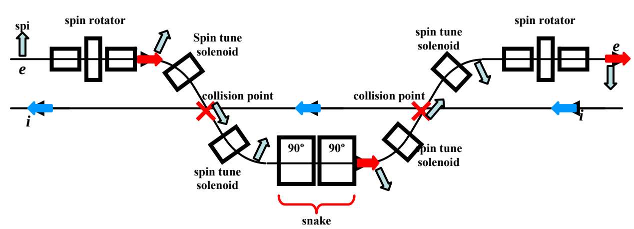

Fig.4: Spin rotation and stabilization in e-ring: spin injected to be vertical in arcs (using Wien filter); spin rotators matched with the cross bends of IPs. 180° solenoids are introduced between IP to inverse vertical spin between arcs of the twisted ring. Spin stabilizing solenoids introduced in sections with longitudinal polarization around detectors.

DESIGN OF $e^{\pm}$ STORAGE RING

Main requirement to e-beam optics design in arcs is to provide a sufficiently strong focusing and low orbit dispersion in dipoles against quantum excitation of horizontal emittance. The x-y coupling control around the ring is required in order to maintain beam aspect ratio at IP matched with that of ion beam. *Spin matching* as a measure to prevent quantum depolarization due to spin sensitivity to particle energy in bends is another critical design condition.

Table 2: Basic parameters of the e-storage ring design

Energy	GeV	3	5	7	10
Circumference	Km	1.5			
Bend radius	m	75			
Dipole field	KG	1.44	2.3	3.2	4.6
Arc radius	m	100			
Damping time	ms	50	12	4	1.5
Source current	mA	1	1	1	1
Accum. current	A	3	3	3	3
Accum. time of e^-	s	15	3.6	1	.5
e^+ injection current	μA				1
Accum.time of e^+	min				10
Energy spread	%	.04	.07	.1	.14
Bunch length	mm	5	5	5	5
β-function in arcs	m	3			
Horiz. emittance,	μm	36	88	88	88
Vert. emittance	μm	1.4	3.6	3.6	3.6
Polarization time*)	h	20	10	2	.33
Eq.polarization**)	%	92	91.5	90	88

3 FORMING ION BEAMS

OVERCOMING SPACE CHARGE AT INJECTION

Stripping injection can be used to stack polarized proton and deuteron beams in the pre-booster after 200 to 400 MeV linac. State of art polarized ion sources and RF linac can deliver 2 mA or higher polarized beam current with 0.3 μm normalized transverse emittance. To minimize the space charge impact on transverse emittance, the *circular painting* technique can be used at stacking. Such technique was originally proposed for stacking proton beam in SNS [6]. In this concept, optics of booster ring is designed strong coupled in order to realize circular (rotating) betatron eigen modes of two opposite helicities. During injection, only one of two circular modes is filled with the injected beam. This mode grows in size (emittance) while the other mode is not changed. Thus, reduction of tune shift by a factor of k will be paid by increase of the 4D emittance by the same factor, but not k^2. The circulating beam should be strongly focused to the stripping foil in order to diminish the Coulomb scattering impact on beam emittance. An RF beam raster is introduced in order to prevent the overheating of the foil by the focused beam.

The low temperature rotating beam can be preserved at succeeding beam acceleration and injection into the large booster and the collider ring. This reduction of the 4D emittance growth at stacking 1-3 Amps of light ions is of a critical importance for effective use of electron cooling in collider ring, since the initial electron cooling time is determined by the 6D emittance value of the injected ion beam.

ELECTRON COOLING

An ERL-based high energy electron cooling (EC) for heavy ion colliding beams in RHIC is developed at Brookhaven National Laboratory [7]. ERL-based EC for ELIC has been described in [8]. An advancement of the cooling scheme for ELIC was use of a circulator-cooler ring as a way to reduce the necessary electron current in 75 MeV ERL. Other challenge of high energy EC is design of electron beam transport system compatible with efficient acceleration and beam alignment. In cooperation with Cooling team of BNL, we explore two concepts of cooling beam transports: a classical scheme with magnetized e-gun but discontinuous solenoid (earlier successfully implemented in Fermilab's cooler of 8 GeV antiproton beam [9]) and SRF gun based non-magnetized, space charge dominated beam [7] (in both schemes the source is photo-cathode based).

4 CONCLUSIONS

A compelling scientific case is developed for a high luminosity, polarized electron-light ion collider, to address fundamental questions in hadron Physics. JLab design studies have led to an approach that promises luminosities up to nearly $10^{35}cm^{-2}s^{-1}$, for electron-light ion collisions at a center-of-mass energy between 20 and 65 GeV. A fundamentally new approach has led to a design that can be realized on the JLab site using CEBAF as a full energy injector into an electron storage ring and can be integrated with the 12 GeV fixed target program for physics. This ring-ring design requires significantly less technological development compared to the ERL-based design, for the same luminosity level. Planned R&D will address open readiness issues.

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